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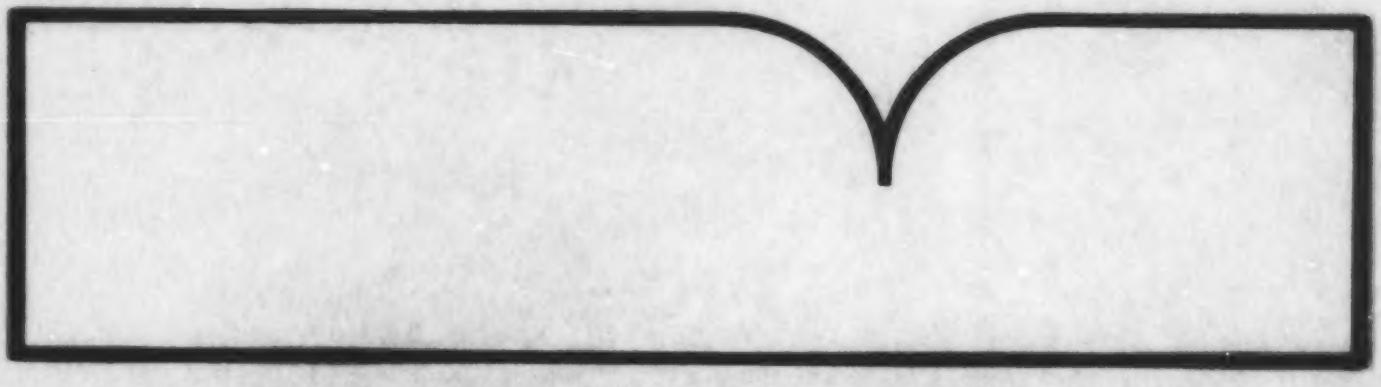

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INPUFF, A MULTIPLE SOURCE PUFF MODEL

by

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16. ABSTRACT

INPUFF is a Gaussian INtegrated PUFF model. The Gaussian puff diffusion equation is used to compute the contribution to the concentration at each receptor from each puff every time step. Computations in INPUFF can be made for a single or multiple point sources at up to 100 receptor locations. In practice, however, the number of receptors should be kept to a minimum. In the default mode, the model assumes a homogeneous wind field. However, the user has the option of specifying the wind field for each meteorological period at up to 100 user-defined grid locations. Three dispersion algorithms are utilized within INPUFF for dispersion downwind of the source. Optionally the user can incorporate his own subroutines for dispersion and plume rise. Removal is incorporated through deposition and gravitational settling algorithms. A software plotting package is provided to display concentration versus time for a given receptor and the puff trajectories after each simulation time.

17. KEY WORDS AND DOCUMENT ANALYSIS

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1. INTRODUCTION

INPUFF is a Gaussian integrated puff model with a wide range of applications. The implied modeling scale is from tens of meters to tens of kilometers. The model is capable of addressing the accidental release of a substance over several minutes, or of modeling the more typical continuous plume from a stack. Computations in INPUFF can be made for multiple point sources at up to 100 receptor locations. In practice, however, the number of receptor locations should be kept to a minimum to avoid excessive run time. INPUFF is primarily designed to model a single event during which one meteorological transition period may occur, such as, an early morning inversion break-up. Up to 144 separate meteorological periods of the same length may be used to characterize the meteorology during the event; this provides a time resolution that ranges from minutes to an hour. The user has the option of specifying the wind field for each meteorological period at up to 100 grid locations or allowing the model to default to a homogeneous wind field.

Three dispersion algorithms are used within INPUFF for dispersion downwind of the source. The user may select the Pasquill-Gifford (P-G) scheme (Turner, 1970) or the on-site scheme (Irwin, 1983) for short travel time dispersion. The on-site scheme, so named because it requires specification of the variances of the vertical and lateral wind direction, is a synthesis of work performed by Draxler (1976) and Cramer (1976). The long travel time scheme is the third dispersion algorithm in which the growth of the puff becomes proportional to the square root of time. Optionally, the user can incorporate his own subroutine for estimating atmospheric dispersion.

INPUFF utilizes the deposition algorithms given by Rao (1982). In the limit when pollutant settling and dry deposition velocities are zero, these expressions reduce to the Gaussian diffusion algorithms.

Sections 2 and 3 below provide a brief description of INPUFF. These sections are discussed in detail in the user's guide (Petersen et al, 1984).

2. FEATURES AND LIMITATIONS

Several requests to the Environmental Operations Branch for assistance in modeling the air quality downwind of incineration ships stimulated the development of INPUFF, a model capable of simulating a moving point source in a spatially variable wind field. The model also possesses the following features which increase its flexibility and range of application:

* Optional stack-tip downwash,
* Wind speed extrapolated to release height,

* Temporally variable source characteristics,
* Temporally and spatially variable wind field,
* Up to 100 receptors,
* Some consideration of terrain effects through the wind field,
* Optional buoyancy induced dispersion,
* Optional deposition and settling,
* Optional user-supplied dispersion parameters,
* Optional user-supplied plume rise, and
* Optional graphics display.

Although INPUFF has several advantages over its continuous plume counterparts, it still retains several limitations, including:

* Wind direction constant with height,
* No consideration of chemical reactions,
* No explicit treatment of complex terrain,
* No consideration of building wake or cavity effects.

3. BASIS FOR INPUFF

3.1 Gaussian Puff Methodology

A graphical representation of the INPUFF model is given in Figure 1. Here the first puff (the puff with the longest trajectory) was first exposed to east-southeast winds, followed by slightly stronger winds from the south and the south-southeast. The second puff was released at the time the winds shifted from east-south-east to south. The third puff was released when winds were from the south-southeast. The stability conditions need not be equal for the various time steps, though in the figure, stability is shown to be fairly constant with time (i.e., the rate of puff growth is constant over the time frame). INPUFF assumes $\sigma_x = \sigma_y$, thus puffs remain circular throughout their lifetime. Puffs A, B, and C represent the location of the three emitted puffs at time t_3.

In Gaussian-puff algorithms, source emissions are treated as a series of puffs emitted into the atmosphere. Constant conditions of wind and atmospheric stability are assumed during a time interval. The diffusion parameters are functions of travel time. During each time step, the puff centers are determined by the trajectory and the in-puff distributions are assumed to be Gaussian. Thus, each puff has a center and a volume which are determined separately by the mean wind, atmospheric stability, and travel time.

3.2 Plume Rise

Plume rise is calculated using the methods of Briggs (1969, 1971, 1973, and 1975). Although plume

rise from point sources is usually dominated by buoyancy, plume rise due to momentum is also considered. Building downwash, and gradual plume rise are not treated by INPUFF.

Stack-tip downwash (optional) can be considered using the methods of Briggs (1969). In such an analysis, a height increment is deducted from the physical stack height before momentum or buoyancy rise is determined. Use of this option primarily affects computations from stacks having small ratios of exit velocity to wind speed.

3.3 Dispersion Algorithms

Three dispersion algorithms are used within INPUFF for dispersion downwind of the source:

* P-G scheme as discussed by Turner (1970),
* On-site scheme formulated by Irwin (1983), and
* Long travel time scheme.

The user has the option of choosing either the P-G or the on-site algorithm (for short travel time dispersion) and specifying when the long travel time dispersion parameters are to be implemented. Optionally, a user-supplied subroutine to estimate dispersion can be used.

Dispersion downwind of a source, as characterized by the P-G scheme, is a function of stability class and downwind distance. Stability categories are commonly specified in terms of wind speed and solar radiation. The on-site dispersion algorithm is a synthesis of Draxler's (1976) and Cramer's (1976) ideas and requires specification of the variances of the vertical and lateral wind directions. The third dispersion scheme is used in conjunction with the other two and is for long travel times in which the growth of the puff is proportional to the square root of time.

3.4 Settling and Dry Deposition

Rao (1982) gave analytical solutions of a gradient-transfer model for dry deposition of pollutants from a plume. His solutions treat gravitational settling and dry deposition of pollutants in a physically realistic manner, and are subject to the same basic assumptions and limitations associated with Gaussian plume models. His equations for deposition and settling were incorporated in several EPA air quality models including PAL-DS (Rao and Snodgrass, 1982). The equations used in INPUFF are the same as those used in PAL-DS except they are cast in terms of travel time instead of wind speed and downwind distance.

4. EXAMPLE

The following example illustrates the use of INPUFF. The simulation consist of twenty 5-minute periods in which the mixing height increases from 500 m to 1100 m during the first sixteen periods and remains constant thereafter. The atmospheric stability is characterized by P-G Class A. The wind speed is 3 m/sec. All meteorological variables are constant during the simulation except mixing height. The source has a stack height of 200 m with a final effective height of 594 m for the plume.

The average concentrations during the 100 minute simulation are shown in Table 1. The highest concentration occurs at 1.2 km downwind (a short travel distance), which is what one would expect during very unstable conditions. However, the peak concentration occurs at 1.6 km downwind, shown in Figure 2. Peak concentrations during the fumigation of the plume are approximately twice the average concentration for the same mixing height. Peak concentrations for receptors downwind gradually decrease. Figure 3 shows the concentration versus time at 3 km downwind. The peak concentration is approximately 10% less than that at 1.6 km.

TABLE 1. 100 minute average concentrations

Downwind Distance (km)	Concentration ($\mu g/m^3$)
0.5	0.028
0.7	0.134
0.9	0.272
1.0	0.315
1.2	0.353
1.4	0.351
1.6	0.331
1.8	0.307
2.0	0.285
2.2	0.265
2.4	0.249
2.6	0.236
2.8	0.224
3.0	0.215

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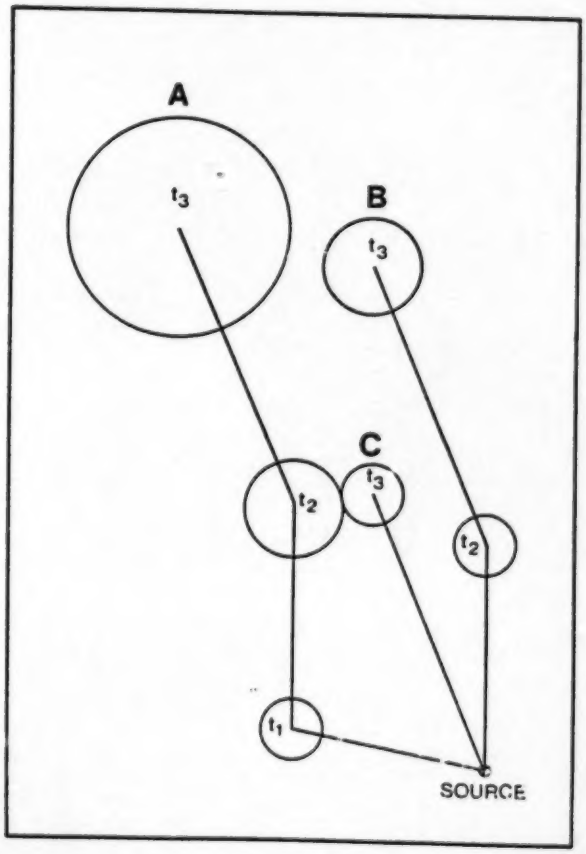

Figure 1. Gaussian Puff Model.

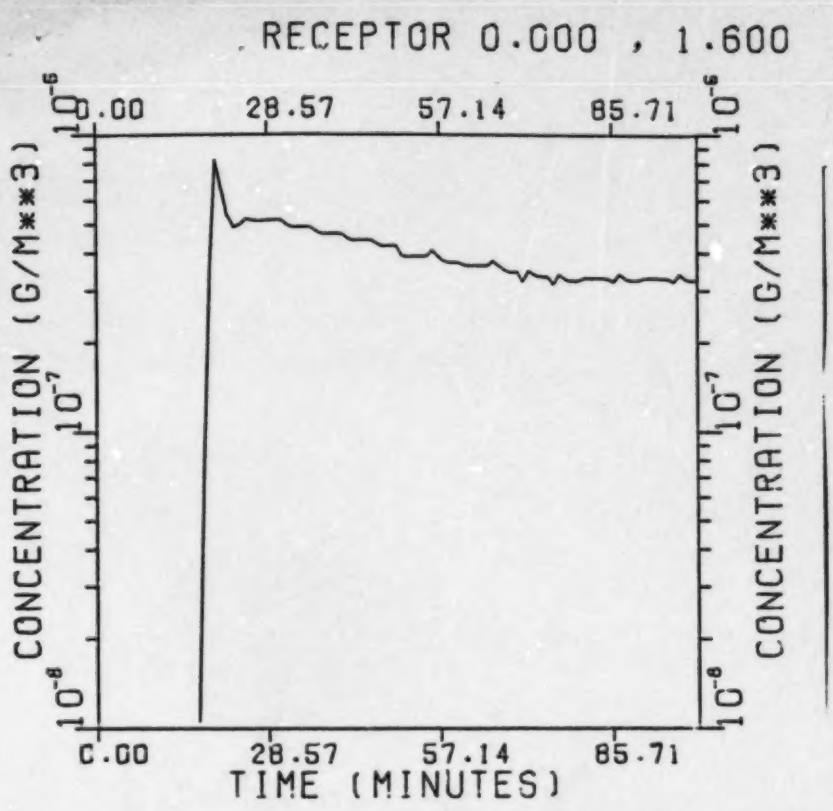

Figure 2. Concentration versus time at 1.6 km downwind.

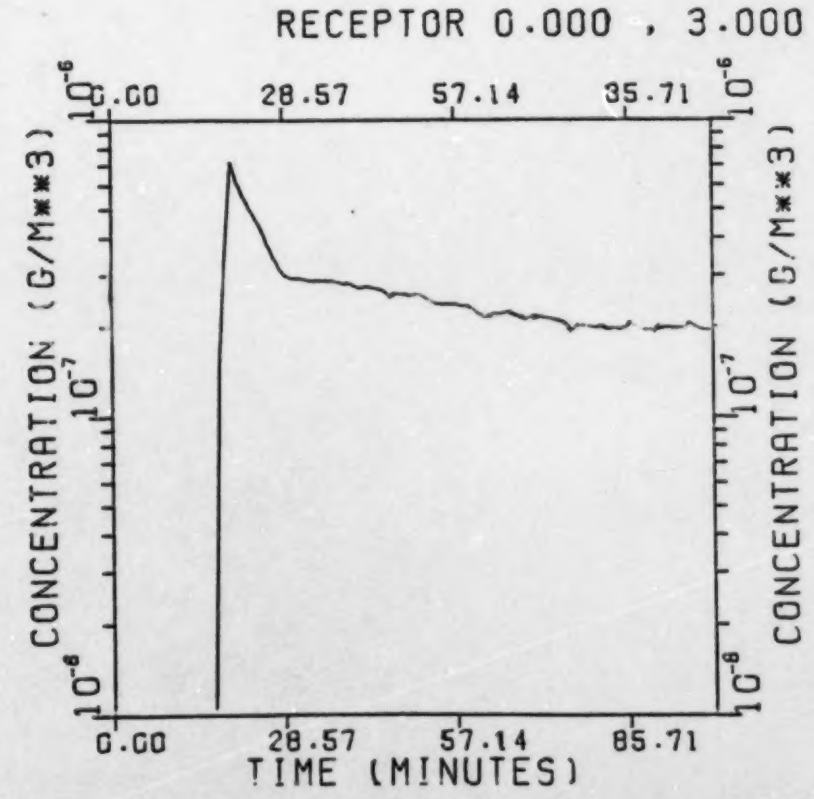

Figure 3. Concentration versus time at 3 km downwind.